EXHIBIT 17

MDHS 77

51415

Asbestos in bulk materials

Sampling and identification by polarised light microscopy (PLM)

Methods for the Determination of Hazardous Substances

Occupational Medicine and Hygiene Laboratory

HSE Health & Safety Executive

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CONTENTS

INTRODUCTION

Definitions and nomenclature

1 Asbestos is a term used for the fibrous forms of several naturally occurring silicate minerals which have been exploited for their useful properties of flexibility, high tensile strength, incombustibility, low thermal conductivity, and resistance to chemical attack. For regulatory purposes in Britain, the Control of Asbestos at Work Regulations (CAWR)[1] define asbestos as any of the minerals chrysotile, crocidolite, amosite, fibrous anthophyllite, fibrous actinolite or fibrous tremolite (see Table 1), or any mixture of them. 'Asbestos-Containing Material' is a term used to describe a material which contains any of these regulated fibrous minerals. The nomenclature and definitions used in this MDHS to describe optical microscope work are based on the RMS Dictionary of Light Microscopy;[2] a glossary of relevant terms can be found in Appendix 1.

Mineralogy of asbestos

2 Silicate minerals are classified by the number and arrangement of silicate tetrahedra in the repeating units of the crystal lattice.[3,4] Chrysotile is classed as a sheet silicate and is a member of the serpentine group.[3,5] The other types of asbestos are chain silicates in the amphibole group of minerals.[4,5] Rocks containing serpentine and amphiboles occur widely on the earth's surface, but only in rare circumstances have conditions favoured the formation of asbestos which occurs in veins. When veins are present in significant quantities (above about 1% of the host rock) commercial extraction of the fibres may be practicable. It is not uncommon for relatively low percentages of amphibole asbestos to be present in other mined products (such as talc and iron ore). Table 1 gives the asbestos and the non-asbestos varieties of the serpentine and the amphibole minerals together with nominal compositions.[5-9] Variations in cation composition not only define the amphibole types, but are also responsible for the observed differences in optical properties within each type. Microscopists should be aware of such variations and their effects on observable refractive indices (RIs); see paragraphs 6 and 50.

Health effects and regulations

3 The regulated asbestos minerals have been associated with various diseases as a result of inhalation, including asbestosis, lung cancer and mesothelioma. Information on medical effects is given in an HSE Medical Series Guidance Note.[10] Information on legislation, product types and control measures is given in Approved Codes of Practice and in HSE Environmental Hygiene Guidance.[11-18] The Department of the Environment has published guidance on asbestos in buildings[19] for building professionals and safety representatives. Attention is drawn to the Asbestos (Prohibitions) Regulations 1992.[20]

Sampling and analytical competence

4 Organisations and personnel undertaking the identification of asbestos should have the necessary facilities, expertise and arrangements for quality assurance to ensure consistent identification of the asbestos minerals (see paragraphs 64 to 68). Evidence for this can be demonstrated by obtaining accreditation from the National Measurement Accreditation Service (NAMAS) for the sampling and identification of asbestos. (A list of accredited laboratories is available from NAMAS at the address given in Appendix 2.) It is important to realise that the validity of each result depends on the competence of the microscope user, and analytical quality cannot be assured by calibration and maintenance of equipment alone.

Table 1 *Varieties of asbestos, their non-asbestiform mineral analogues, and nominal compositions (adapted from Hodgson[6] and Walton[9])*

Asbestos Variety	*Non-asbestos Mineral Analogue*	*Nominal Composition*
Serpentine group of minerals		
Chrysotile	Lizardite, Antigorite	$Mg_3(Si_2O_5)(OH)_4$
Amphibole group of minerals		
Crocidolite	Riebeckite	$Na_2Fe_3^{2+}Fe_2^{3+}(Si_8O_{22})(OH)_2$
Amosite	Grunerite	$(Fe^{2+},Mg)_7(Si_8O_{22})(OH)_2$
Fibrous anthophyllite	Anthophyllite	$(Mg,Fe^{2+})_7(Si_8O_{22})(OH)_2$
Fibrous actinolite	Actinolite	$Ca_2(Fe^{2+},Mg)_5(Si_8O_{22})(OH)_2$
Fibrous tremolite	Tremolite	$Ca_2Mg_5(Si_8O_{22})(OH)_2$

Principle

5 A representative sample of the material thought to contain asbestos is collected for examination. In the analytical laboratory, this is examined by eye, followed by more detailed examination using a low power (8x to 40x) stereo microscope. One or more representative sub-samples may be prepared mechanically and/or chemically for further examination. Fibres observed in the course of these examinations are categorised tentatively on the basis of morphology and certain physical properties. Each fibre type so recognised is sampled by selecting a few fibres or bundles, and these are mounted in a refractive index (RI) liquid chosen to match the most likely asbestos type. The fibres then are positively identified as one of the six regulated asbestos types on the basis of their detailed optical properties using polarised light microscopy (PLM) with magnifications from about 80x upwards as appropriate.

Scope and limitations

6 This MDHS summarises the appropriate sampling procedures (paragraphs 8 to 15) and describes the subsequent identification of the six regulated types of asbestos by PLM (paragraphs 16 to 49). The method is

suitable for all common asbestos-containing materials, and can distinguish between asbestos fibres and elongate mineral fragments or other materials in almost all situations. However, difficulties may occur in distinguishing between tremolite and actinolite or between tremolite and anthophyllite (see paragraph 50); in such cases electron microscopy with energy dispersive X-ray analysis and/or electron diffraction techniques, X-ray diffraction or infra-red spectroscopy may be required to provide additional information. Also, information is given on asbestos which has been subjected to heat[21-23] (see paragraph 53) and on other types of fibre which may be encountered[24] (see paragraphs 54 to 62).

Sensitivity

7 With careful application of this method, a single fibre may be found in a few milligrams of dispersed material. In practice, for a fibre about 100 μm long by about 2 μm diameter, this implies a detection limit in the order of 1 ppm by mass. With such a sensitive method ***it is important that all procedures be designed to avoid cross-contamination.***

SAMPLING

Strategy

8 The aim of the sampling, and of the strategy to be adopted, should be established before any site-work is undertaken. The strategy may vary depending on the primary aims, ranging from sampling a single suspect material, to the survey and assessment of a building complex. In the larger surveys the number of samples, and the locations of sampling points, are important issues; the strategy developed will depend upon several factors,[19] including requirements of owners or occupiers. An essential part of the strategy is assessment of the precautions required by CAWR (see paragraph 9). Reports on sampling should refer to the aims, strategy and extent of the survey, and written protocols should be prepared which detail procedures for site surveys to identify asbestos-containing materials. For a complete assessment, all suspect materials should be sampled unless equivalence to other identified materials on the site can be established. However, it is important not to sample unnecessarily; thus sampling may be avoided altogether if it is decided to treat all suspect materials as containing amphibole asbestos. A list of commonly used products known to contain asbestos is a useful starting point, and this and other general information for the surveying of asbestos-containing materials are given in Department of the Environment guidance.[19]

Precautions

9 As required under CAWR,[1] dust release in sampling must be reduced to as low a level as is reasonably practicable, and an assessment in respect of likely dust release will dictate the need for precautionary measures. These may include use of personal protective equipment, isolation of the sampling area, wetting of material to suppress dust release, and an appropriate cleaning process. After sampling, any broken material with potential to cause airborne dust should be sealed, and any remaining dust or debris should be removed by wet wiping or by using an approved 'type H' vacuum cleaner.[25] Immediately after collection, samples should be double sealed in suitable containers which will not release dust when subsequently handled. Any disposable material used in sampling, or dust created while sampling, should be treated as if contaminated by asbestos (see also paragraph 15). Sampling should not impair the structural integrity of the building or plant. Air monitoring may be appropriate in certain sampling situations for reassurance purposes.[13,26]

Apparatus

10 A variety of tools may be needed for sampling, such as a core sampler, hand saw, pliers, knife, screwdriver, and hand-held spray to wet the material for dust suppression. The use of power tools which may give rise to excessive dust should be avoided. Plastic bags, wet cloths for cleaning, and commercial fillers for sealing exposed asbestos, generally will be required. (The use of polyurethane foam fillers must be avoided on or near sources of heat because toxic fumes are released.) For the reason outlined in paragraph 7, ***care must be taken to prevent cross-contamination between samples.*** This can be achieved by adopting suitable cleaning procedures after the use of each tool, and by using separate containers for each sample.

Homogeneous commercial products

11 In manufactured products containing asbestos, such as boards, sheets, cement pipes, textiles, ropes, friction products, plastics and vinyls, mastics, sealants, bitumen roofing felt and gaskets, it can be assumed that the asbestos is uniformly distributed throughout the material. Hence, in most cases, a relatively small sample can be taken as being representative of the whole (see also Annex 2 in Ref 19). For comparatively brittle materials, wetting or taping each side at the point of breakage can help to suppress dust release.

Insulation and spray materials

12 Frequently insulation was wet mixed on site, so that the asbestos content can be variable. Subsequent repairs and patching may add to this variability. After a visual examination to assess any apparent areas of different material, samples of each area should be taken with the aim of collecting a group of samples which is representative of the whole material. Each sample should be taken to the full depth of insulation, for example by use of a coring tool of approximately 25mm diameter (which is equivalent to an area of about $5cm^2$; see also Annex 2 in Ref 19). This could involve cutting through layers of wire mesh (coring tools around one half inch diameter may help to overcome this difficulty).

Surface dust

13 The sampling technique adopted will depend on the nature and location of the surface under consideration. A smooth non-porous surface can be wiped with the inside of

a plastic bag which is then reversed. Alternatively, careful scraping or wiping with adhesive tape or a membrane filter may be used to sample the dust. (Glass fibre or cellulose filters should not be used because they may introduce fibres into the sample.) For uneven or porous surfaces with little visible or loose dust, a microvacuum technique using a personal sampling cassette and pump may be preferred. Dust collected on membrane filters can be removed by washing, and then dried for analysis. It may be difficult to remove the sample from an adhesive tape; however, some forensic tapes have water soluble coatings and thus are suitable for this purpose. The use of brushes generally is not recommended because of the ease with which dust is made airborne and the possibility of cross-contamination.

Sample documentation

14 Whenever a sample is collected it should be labelled uniquely, and adequate documentation should record the date, site address, room, plant or area location, and also a general description of the material. Copies of this documentation will accompany the sample to the laboratory. Where appropriate, the sampling position at the site location should also be identified uniquely.

Sample packaging and transport

15 Each sample collected should be placed in an individual airtight container which is sealed and labelled with a unique identifier. Because the outside of the container may be contaminated in the sampling procedure, the contained sample or samples should be placed in a second airtight container which should bear an appropriate warning label (see Appendix 3). In general, it is possible to transport small numbers of bulk asbestos samples to the laboratory for PLM analysis, but if quantities exceed 5 litres, further regulations will apply (see Appendix 4). Following analysis, appropriate packaging and labelling is required for disposal of the asbestos samples at a licensed waste facility (see Appendix 5).

ANALYSIS

Procedure

16 This MDHS describes analytical techniques which have been shown to give reliable and reproducible results. Alternative methods can be used if equivalence in terms of detection and identification can be demonstrated. ***All procedures should be designed to avoid cross-contamination between samples.*** Identification of the asbestos fibres should be based on the following analytical sequence (see also Figure 1, and the detailed procedures given in paragraphs 24 to 49):

(a) a preliminary visual examination of the whole of the bulk sample is made to assess the sample type and the required sample treatment (if any): where possible a representative sub-sample may be taken at this stage;

(b) sample treatment is undertaken (if required) to release or isolate fibres;

(c) a detailed and thorough search under the stereo microscope is made to classify the fibre types present;

(d) representative fibres are mounted in appropriate RI liquids on microscope slides;

(e) the different fibrous components are identified using PLM.

If no asbestos is identified by these procedures, additional searches for small asbestos fibres on random sub-samples of a few milligrams are undertaken using PLM (see Figure 1 and paragraph 32).

Precautions

17 ***Handling procedures should be such as to minimise the risk of releasing fibres into the laboratory.*** Visual and stereo microscope examinations, and sample preparation, should be conducted inside a fume cupboard, or in a suitable cabinet. Sealed bags or containers of asbestos samples should be opened only inside such a cabinet or fume cupboard. Heavy duty plastic bags are recommended for temporary containment of waste prior to final disposal in properly labelled bags (see Appendix 5). Chemicals used in sample preparation are subject to the Control of Substances Hazardous to Health (COSHH) Regulations 1988,[27] and should be fully assessed prior to use. When the handling of asbestos-containing materials is frequent, airborne exposures should be assessed as required by CAWR.[1] In any case, it is recommended that regular air monitoring (on a monthly basis) is conducted in the preparation/identification area, and that the results are recorded.

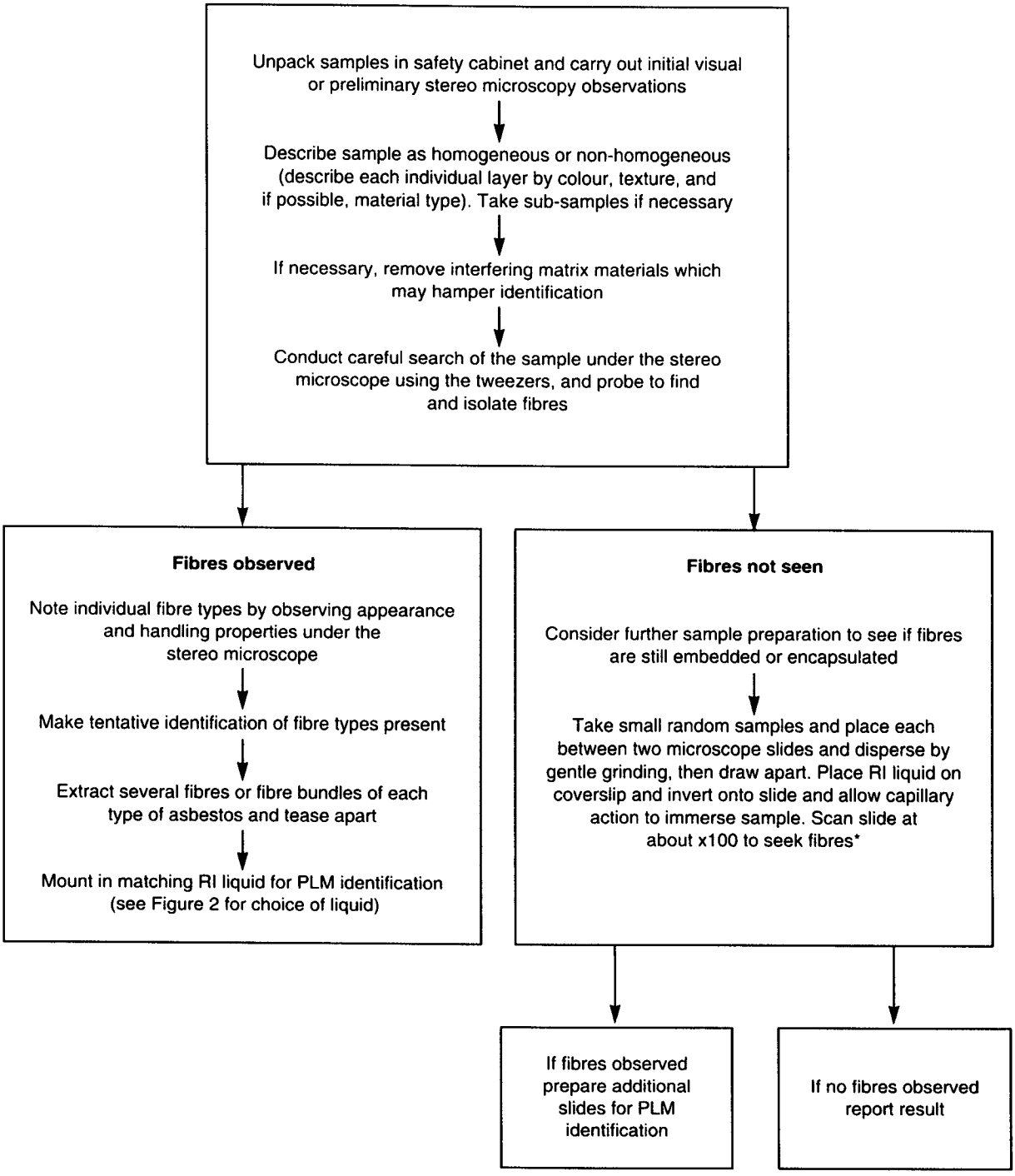
Laboratory requirements

18 Fume cabinets should conform to BS7258,[28, 29] and in practice should have a minimum face velocity of 0.5m/s. Recirculating air cabinets must draw air away from the microscopist, and be fitted with a high efficiency ('HEPA') filter. Ergonomic laboratory design is recommended for easy movement between areas used for sample preparation and analysis. Adjustable seating to allow the microscopist to sit with a relaxed and comfortable posture is particularly important. A background shield may be required if other sources of light or activity interfere with the microscopist's comfort or concentration. Ideally, to avoid eye fatigue, the peripheral view beyond the microscope should be distant and without direct sunlight.

Reagents

19 Various reagents may be necessary for sample treatment. Acetic acid, hydrochloric acid, sodium hydroxide, and acetone or other organic solvents, are used commonly. Liquids of known RI are needed (see the list of suppliers in Appendix 2). To identify the six asbestos minerals, a minimum of five high dispersion liquids having RI values 1.550, 1.605, 1.640, 1.670 and 1.700 is used commonly, but other RI liquids may be required to achieve RI match between fibre and liquid (see also paragraph 49). The commercially available RI liquids have a stated shelf

Figure 1 *Initial examination of samples*



**Note: Very fine fibres were used in vinyl asbestos tiles and may be present in dusts: thus, higher magnifications may be required to detect asbestos.*

**Note: Search for chrysotile in a liquid to give high contrast (eg water, or RI of 1.67).*

life. For the reason outlined in paragraph 7, contamination by particles and fibres during use should be avoided; therefore, it is recommended that the liquids be checked on a regular basis in the quality control programme, and that suitable records of such checks be kept[30] (see also paragraph 66).

Sample preparation and analytical equipment

20 Apparatus required for sample treatment will include probes and needle point tweezers, and also may include glass beakers, disposable containers or washable Petri dishes, an ultrasonic bath, boiling tubes, vacuum filtration flask, pump and filter holder with appropriate filters (glass fibre and cellulose filters are not recommended because they may introduce fibres into the sample). Pliers, a file and a saw may be needed to break the sample, and a pestle and mortar may be needed to release fibres from matrices. For analysis the following equipment is required: glass slides, cover slips,[31] probes, tweezers and lint-free tissues.

Microscopes

21 A low powered stereo microscope is required for the initial search. A polarised light microscope capable of Koehler (or Koehler type) illumination is needed for fibre identification: if it has an in-built light source, the instrument must have an independently centrable condenser; also required are:

(a) a focusable condenser with numerical aperture (NA) greater than that of any objective used;

(b) a condenser iris;

(c) a polariser;

(d) a removable analyser;

(e) a removable first order red compensator (of retardation approximately 530 nm);

(f) a level rotating and independently centrable stage (or a level rotating stage and centrable objective);

(g) a focusing eyepiece (preferably non-rotatable) containing a cross-hair graticule defining the vibration directions of the polariser and the analyser;

(h) a Bertrand lens or focusing phase telescope;

(i) eyepieces of 8x or higher magnification (those with high eyepoints and flexible caps for spectacle wearers are advantageous);

(j) objectives of 10x (minimum NA = 0.2) and higher magnification (higher NA).

Note: in some microscopes filters may reduce the light intensity and should be removed for satisfactory PLM work.

Additional equipment for RI assessment

22 One of the following accessories is required to aid the assessment of fibre RIs by producing intense dispersion staining colours (see also paragraph 48):

either (a) a dispersion staining objective (10x magnification) with a central stop in its back focal plane, used in conjunction with the condenser iris (which is capable of producing a pin-hole aperture);[24]

or (b) positive phase contrast objective (10x magnification or greater), and condenser with matching centrable phase annuli.

Reference samples

23 Reference samples of the six asbestos types listed in paragraph 1, and commonly occurring non-asbestos fibres including natural organic fibres (such as cotton and hair), synthetic organic fibres (such as aramid, polyester and rayon), man-made mineral fibres (for example, mineral wool and glass fibre), and naturally occurring mineral 'fibres' (such as wollastonite and diatom fragments), should be held by the laboratory. Asbestos reference samples suitable for polarised light microscope analysis[32] have been prepared under contract to the Health and Safety Executive and are available from the supplier listed in Appendix 2. Other asbestos reference materials may be useful. It is recommended practice for analytical laboratories to establish their own libraries of in-house standards related to their work (see also paragraph 67).

DETAILED ANALYTICAL PROCEDURES

Initial examination

24 The entire sample should be examined by eye to describe the type of material or product present, and to establish whether or not visible fibres are present. The natures of any binder materials should be noted, as they may influence treatment of the sample. Examination of insulation samples and many manufactured products under the stereo microscope will aid the detection of fibres and allow some initial assessment of the number of fibre types present. Certain products such as vinyl floor tiles, and settled dusts, may contain asbestos fibres which are too fine to be detected in this initial examination. The appearance, colour and texture of the sample, and any fibre types observed, should be recorded. For non-homogeneous samples, each separate layer, part or variant may require individual description. Sample preparation and the analysis of the sample are dependent on the quality of the initial visual examination. Also, adequate description of the appearance of the sample is important in establishing where, or in which part, the asbestos material is present.

Sample treatment

25 The purpose of sample treatment is to release fibres from any matrix and to remove fine particles adhering to the fibres (both of which obscure optical effects and hinder identification). Non-friable samples will need to be broken (with tools if necessary) and the newly fractured edges inspected under the stereo microscope to reveal protruding fibres. Some hard pieces may require grinding. Surfaces

and edges may be abraded to release fibres. ***Routine procedures for sample treatment used in the laboratory should be fully documented. Any deviations from these procedures for particular samples should be recorded.***

26 Dilute acetic acid (eg 50%) or cold dilute hydrochloric acid (eg 10%) may be used to remove calcium carbonate and calcium silicate, which are common binders in insulation and asbestos boards, and which are used as fillers in floor tiles. Sufficient acid should be added in small aliquots for several minutes or until effervescence stops. Fibre release may be aided by stirring or by ultrasonic treatment. The sample is then filtered and repeatedly washed with water. (Residual acid may degrade the fibres and affect the optical properties, and small crystals of salts will form.) The sample may be rinsed with acetone or other volatile solvents to reduce drying time.

27 Organic binders (for example, in plastics, bitumen, resin or rubber products) may require prolonged treatment in solvents. An effective solvent for any single sample can only be established by trial and error. Some organic binders may be removed by ignition at 400°C, but the optical properties of the asbestos fibres may be modified (see paragraph 53).

Stereo microscopy

28 The original samples or portions of sample that have undergone sample treatment should be examined using the stereo microscope. For many asbestos samples a low power stereo microscope (10x) is suitable, but for other samples higher magnifications are sometimes necessary to examine detected fibres. The aim is to detect small fibre bundles, or individual fibres, and to assess the proportion of fibres present and tentatively assign fibre types based on their appearance. This is usually achieved by placing the sample in a suitable container and performing a detailed search of the whole sample using needles or tweezers to separate the different fibrous components from the matrix. These fibres are then observed under the stereo microscope and their appearance noted. The care and vigilance with which the sample is examined at this stage are important in detecting trace quantities of asbestos. Representative fibres or fibre bundles can be selected and mounted for PLM.

29 Layered samples should be described by their appearance and each layer noted as a separate entity. Other types of non-homogeneous samples will require detailed visual examination. A rigid sample (such as a tile) should be broken, and the surfaces and edges scraped. All observations should be recorded.

30 Generally asbestos is recognised by the fineness of its fibres (see paragraph 37), which often are present in closely packed bundles of fibrils that will divide along their length when pressure is exerted on them with a probe or tweezers. A competent analyst will be familiar with characteristics such as distinctive surface lustre, flexibility and tensile strength, as shown in Figure 2. Initial tentative identification of the fibres at this stage will be confirmed or refuted by subsequent examination using PLM.

Preparation of samples for PLM

31 A tentative identification based on the stereo microscopy evaluation is used to select the most appropriate RI mounting liquid. Fibres should be dry and relatively free from other particulate matter. Representative fibres or fibre bundles are chosen and are placed on a clean microscope slide into a drop of RI liquid, and a clean cover slip is lowered gently onto the slide. The RI of the liquid selected should be close to one of the two observable fibre RIs (see paragraph 49 and Figure 3) for positive identification (for example 1.550 for chrysotile, 1.670 for amosite and 1.700 for crocidolite).

32 For bulk samples in which no fibres have been seen using the stereo microscope, or no asbestos fibres have been identified by PLM, tweezers or probes should be used to take random sub-samples after the bulk sample has undergone suitable treatment (if necessary). At least two microscope slide preparations should be made with appropriate RI liquids for examination by PLM. Any large agglomerates should be teased apart, or may be ground gently between two microscope slides, to give an even distribution. Selection of large particles or fibre bundles may cause tilting of the cover slip and should be avoided. The amount of sample distributed should be such that the appearance and properties of individual fibres are not obscured by other particles.

Asbestos identification by PLM

33 Identification of a single asbestos fibre requires the assessment of the following properties in the stated observation modes.

Property	*Observation mode*
(1) Morphology	All modes
(2) Colour and pleochroism (if present)	Polariser only
(3) Birefringence (anisotropic behaviour)	Crossed polars
(4) Extinction characteristics	Crossed polars
(5) Sign of elongation	Crossed polars with first order red compensator
(6) RI assessment	Normally using a dispersion staining, or phase contrast, objective with polariser only

The above order facilitates the assessment of the listed properties in a logical sequence. The microscope is adjusted to give Koehler illumination, the stage is centred, and a polariser (usually adjusted to the E-W position) is inserted below the condenser. Under these conditions morphology, colour and (with stage rotation) pleochroism can be observed. The analyser is then inserted (to give crossed-polars) and the stage is rotated to observe

Figure 2 *Use of physical properties and appearance under the stereo microscope to determine choice of RI liquid for PLM identification of asbestos fibre type*

Physical property/appearance						
Colour	Colourless/White	Colourless/White to Grey Brown			Greenish-grey	Deep Blue
Texture	Soft with bundles of sinuous fibres	Soft or harsh; may appear as easily visible parallel fibre bundles			Soft or harsh with parallel fibre bundles	
Appearance	Flexible fibres which cling to tweezers	Straight fibres easy to handle			Straight fibres easy to handle	
Lustre	Silky	Vitreous	Vitreous	Vitreous	Vitreous	Metallic (dark and highly reflective)
Tensile strength	High	High	Medium	Low	Low	High
Tenacity	Flexible	Flexible	Flexible	Flexible	Flexible	Flexible
Elasticity	Inelastic	Elastic	Elastic	Elastic	Elastic	Elastic
Tentative asbestos type	Chrysotile	Amosite	Anthophyllite	Tremolite	Actinolite	Crocidolite
RI liquid for test	1.550	1.670	1.605	1.605	1.640	1.700

birefringence and the extinction characteristics. With the polars still crossed, a first order red compensator is inserted and the stage is rotated to determine the sign of elongation. Finally the RIs of the fibre are assessed by dispersion staining to see whether or not the values are typical and consistent with published data. This may be achieved by observing the dispersion colours at the interface between the fibre and the RI liquid; the most commonly used techniques require that the analyser and compensator be withdrawn, the illumination be increased, and an objective with a central stop or phase ring in the back focal plane be inserted together with an appropriate condenser stop (paragraphs 22 and 48).

34 ***In practice any other sequence may be used provided that all of the properties are observed under the correct conditions.*** For instance, if it is difficult to find the fibres on the prepared mount, or the sample is dominated by non-asbestos fibres, or a random sample is being searched, the sample should be scanned with the microscope in modes 3, 4, 5 or 6 above to detect the asbestos fibres.

35 The observations made of the morphology and the optical properties of the fibre are recorded. Identification is based on comparing the recorded observations on the fibres selected for analysis (and mounted in the appropriate RI liquid) against the properties of asbestos reference standards (which may be in the form of a table such as Figure 3, derived from such standards). A close match between the optical properties of the sample fibre and the asbestos standard will normally be achieved. Further representative fibres will need to be analysed if the observations are inconclusive, or if more than one type of fibre was found in the stereo or PLM analysis.

36 An example of a suitable analytical sequence is given in Figure 1. Optical properties of asbestos are summarised in Figure 3, and more detailed descriptions of the optical properties required to positively identify asbestos minerals follow in paragraphs 37 to 49. Details of the technique by which these properties may be best observed by the analyst are also included. Common problems which arise during identification are discussed in paragraphs 50 to 63. Descriptions of the physics behind the modes of operation, and of the optical properties observed, are beyond the scope of this method and can be found in various standard texts.[33, 34]

Morphology

37 The amphibole minerals which form asbestos also occur in non-fibrous forms.[35] These non-fibrous forms are listed in Table 1 and can occur as, or be broken into, fragments which are long and thin, some of which may satisfy the regulatory definition for fibre counting.[26] However, the asbestos regulations only apply to the asbestos forms of the minerals. (Studies indicate that the biological potencies of such non-fibrous forms are lower than for the asbestos forms of the minerals.[36]) In recent years a more detailed description for asbestiform morphology has been developed and appears in the literature.[37, 38] This is reproduced below and can be used to distinguish between asbestos fibres and non-

Figure 3 *Properties used to identify asbestos by PLM*

Asbestos type		Chrysotile	Amosite	Anthophyllite	Tremolite	Actinolite	Crocidolite
RI liquid		1.550	1.670	1.605	1.605	1.640	1.700
Property							
Morphology		Fibrous	Fibrous	Fibrous	Fibrous	Fibrous	Fibrous
Pleochroism	Fibre parallel	None	None	None	None	Green	Blue
	Fibre perpendicular	None	None	None	None	Grey	Grey
Birefringence		Low	Moderate	Moderate	Moderate	Moderate	Low/anomalous
Extinction		Complete, or undulose with curved fibres; parallel	Complete; parallel	Complete; parallel	Complete; parallel or small angle	Complete; parallel or small angle	Complete; parallel
Sign of elongation		Usually positive (length slow)	Positive (length slow)	Positive (length slow)	Positive (length slow)	Positive (length slow)	Usually negative (length fast)
Dispersion Staining Objective Colours	Fibre parallel	Purple	Yellow	Yellow	Yellow	Yellow-brown	Blue
	Fibre perpendicular	Blue	Purple-red	Orange	Blue	Blue-purple	Blue
Phase Contrast Objective Colours	Fibre parallel:						
	fibre colour	Pale-blue	Grey	Dark-grey	Dark-grey	Dark-grey	Blue
	halo colour	Orange	Yellow	Orange	Yellow	Yellow	Red-brown
	Fibre perpendicular:						
	fibre colour	Pale-blue	Blue	Blue	Blue	Blue	Blue
	halo colour	Orange	Orange	Orange-yellow	Orange	Orange	Red-brown
Refractive Index Ranges	$n\alpha$	1.537-1.554*	1.670-1.675*	1.596-1.654 +	1.599-1.620 +	1.619-1.658 +	1.680-1.692*
	$n\gamma$	1.545-1.557*	1.683-1.694*	1.625-1.667 +	1.622-1.641 +	1.641-1.677 +	1.683-1.700*

(NB: Fibre parallel or fibre perpendicular describes orientation with respect to the polariser. Dispersion colours relate to the HSE reference standards.[32] RI ranges marked * were obtained from commercial asbestos fibre;[40] RI ranges marked + were obtained from non-commercial fibres.[41])

asbestiform fragments (see also paragraphs 51 and 52):

"Under a light microscope, the asbestiform habit is generally recognised by the following characteristics:

a range of aspect ratios ranging from 20:1 to 100:1 or higher for fibres longer than 5 μm;

capability of splitting into very thin fibrils;

two or more of the following:
- parallel fibres occurring in bundles
- fibre bundles displaying frayed ends
- fibres in the form of thin needles
- matted masses of individual fibres, and/or
- fibres showing curvature."

Colour and pleochroism

38 Colour and pleochroism are observed using plane polarised light. Pleochroism is defined as a change in colour of the fibre with orientation relative to the vibration plane of polarised light. Crocidolite has a natural strong absorption which gives a dark blue colour when parallel to the polariser changing to pale blue-grey when perpendicular, as the fibre is rotated. Actinolite often has a natural green colour and changes from green parallel to the polariser to pale green, grey or yellow when perpendicular to the polariser. These properties are important in the identification of crocidolite and actinolite (Figure 3). The other four asbestos types show little colour contrast under plane polarised light, unless exposed to heat (paragraph 53).

39 Alternatively, pleochroism can be detected by orienting a fibre at 45° between crossed polars. The colour of the fibre is observed as the polariser (or analyser) is rotated a small angle each way from the crossed polar position. Any difference in colour between the two directions of rotation indicates that the fibre is pleochroic.[33] This is a very sensitive test of pleochroism, and is convenient to perform when observing birefringence and angle of extinction using crossed polars.

Birefringence

40 The numerical difference between the highest and lowest RIs of a mineral is known as the birefringence. When a particle with more than one RI is observed between crossed polars with its planes of vibration at 45° to those of the polariser, interference colours are observed against the dark background. For asbestos these interference colours depend on the fibre thickness, and on birefringence.

41 Between crossed polars, an asbestos fibre aligned at 45° to the polariser vibration direction should be clearly visible. Chrysotile has low birefringence and gives a grey colour for thin fibres, and a white colour or sometimes higher first (or even second) order colours for thick fibres. Crocidolite has a low birefringence and strong pleochroism which results in anomalous interference colours from grey to pale blue or sometimes a brown. The other amphibole asbestos fibres have moderate birefringence, giving white interference colours for thin fibres and higher first or second order colours for thick fibres. Fibres with a variable thickness, for example with wedge shaped cross-sections, will show parallel bands of colour along their lengths representing lower interference colours for the progressively thinner sections.

42 Isotropic materials do not polarise the light transmitted through them and therefore are distinguished easily from asbestos. Between crossed polars such isotropic materials (for example man-made mineral fibres) are barely visible, but will be seen easily with the first-order red compensator in place, or with slightly uncrossed polars. Interference colours can be used to distinguish asbestos from some natural organic fibres, which may show non-uniform interference along the fibre and incomplete extinction.

Angle of extinction

43 As the microscope stage is rotated through 360°, an asbestos fibre viewed between crossed polars will disappear from view or 'extinguish' at four positions each 90° apart, while at 45° between each extinction interference colours should be visible. Many fibres, including asbestos, generally show complete extinction when parallel to the vibration planes of the polariser or the analyser. Chrysotile, amosite, crocidolite and anthophyllite show straight or parallel extinction when the fibre is parallel to the vibration orientation of the polariser or analyser (which are at right angles to each other and normally aligned E-W or N-S respectively). Actinolite and tremolite asbestos exhibit parallel or very nearly parallel (less than 5° from parallel) extinction (see also paragraphs 51 and 52).

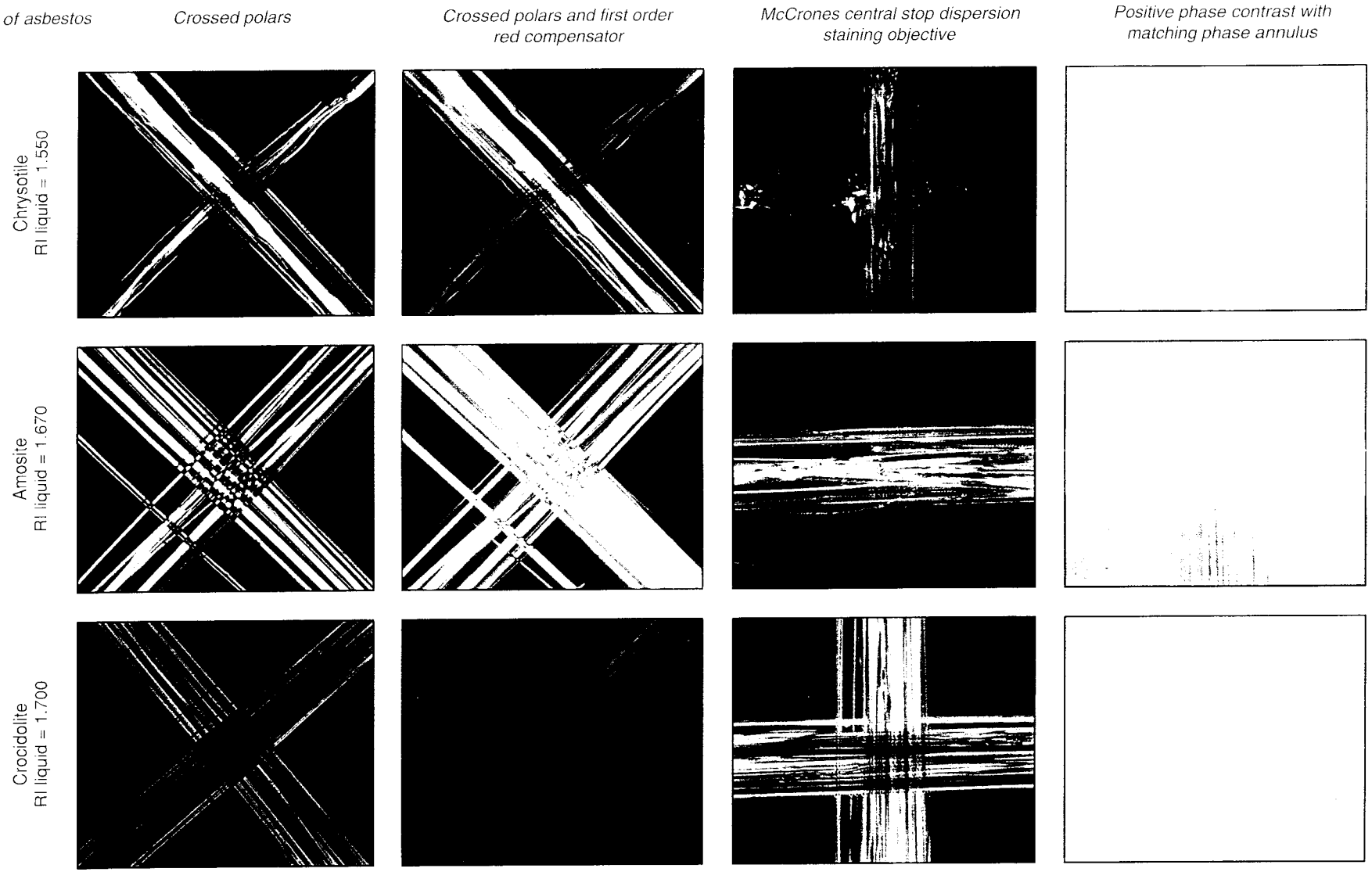
Sign of elongation

44 The sign of elongation describes the relationship between fibre shape and optical properties. The two available vibration orientations are parallel to the long axis and perpendicular to it. If the high RI vibration plane (slow ray) is parallel to the long axis, then the fibre is described as positive (or length slow); if the low RI vibration plane (fast ray) is parallel to the long axis, the fibre is described as negative (or length fast). Between crossed polars, with the first order red compensator inserted at 45°, the sign of elongation can be determined by observing the colours of fibres which previously had given grey or white first order interference colours between crossed polars. For a compensator with the slow direction (usually marked) in the NE-SW direction, the colours observed are as follows:

Positive (length slow) fibre	blue-green with fibre NE-SW orange-yellow with fibre NW-SE
Negative (length fast) fibre	orange-yellow with fibre NE-SW blue-green with fibre NW-SE

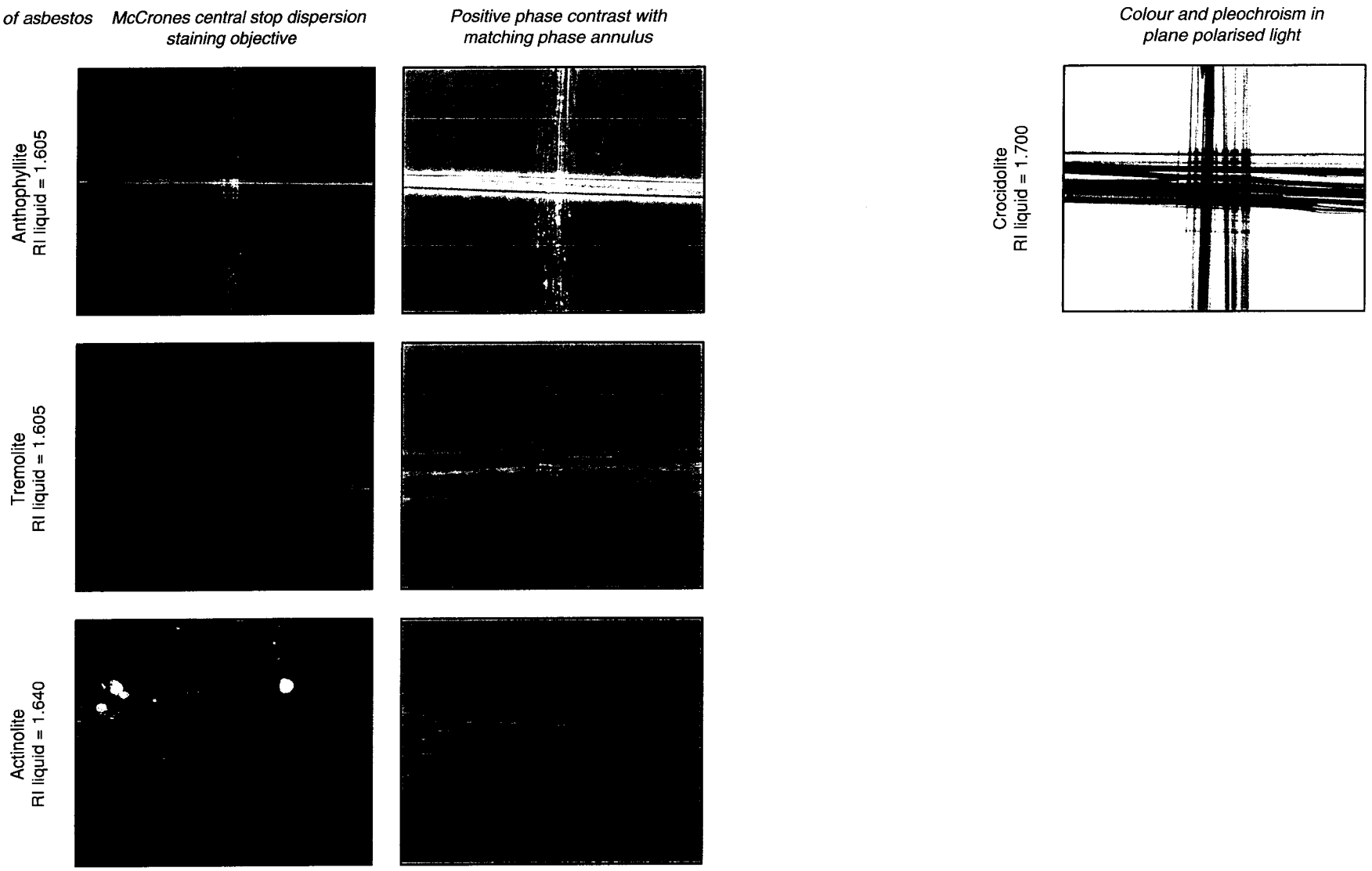
Crocidolite is the only one of the six regulated asbestos types which generally has negative sign of elongation (length fast). However, exposure to heat of about 300°C or higher may change the sign of elongation of crocidolite to positive (length slow); see paragraph 53.

Plate 1 HSE asbestos reference samples viewed by polarised light microscopy



For a compensator with the slow direction in the NE-SW orientation and polariser aligned in the E-W direction. All phase contrast dispersion mounts used the Series B (1.556, 1.680, 1.692, 1.640, 1.604, 1.604) RI liquids, and McCrones central stop dispersion staining mounts used the Series E high dispersion RI liquids (as given). Approximate magnification is x 100.

Plate 2 HSE asbestos reference samples viewed by polarised light microscopy



For a compensator with the slow direction in the NE-SW orientation and polariser aligned in the E-W direction. All phase contrast dispersion mounts used the Series B (1.556, 1.680, 1.692, 1.640, 1.604, 1.604) RI liquids, and McCrones central stop dispersion staining mounts used the Series E high dispersion RI liquids (as given). Approximate magnification is x 100.
Note: crossed polars and crossed polars with a first order compensator plate appearances for anthophyllite, tremolite and actinolite are the same as for amosite.

Refractive index (RI)

45 The RIs of an asbestos fibre are assessed by mounting the clean separated fibre in a liquid of known RI and orienting it either parallel or perpendicular to the polariser vibration direction. One or more observations are conducted to determine whether the RI of the fibre is higher than, lower than or equal to, that of the mounting liquid. The types of observation that can be made are:

(a) Relief;

(b) Becke line;

(c) Dispersion staining colours.

Observation (c) alone is sufficient if a phase contrast or a dispersion staining objective is used and the fibre is mounted in a liquid close to RI match point so that dispersion staining colours can be observed. When dealing with an atypical sample, (a) and (b) are simple observations which can be used to choose a suitable mounting liquid such that the RIs of fibre and liquid are close to match point.

Relief

46 Relief is the term used in microscopy to describe visible contrast between a particle and its mounting medium. The greater the relief, the greater the RI difference between the particle and the mounting liquid. Therefore, if the correct RI liquid has been chosen, little relief should be present and it may be difficult to find asbestos fibres using plane polarised light. If high relief is observed, there is little point in trying to observe dispersion staining colours and a different RI liquid mount should be prepared. It should be noted that relief can be increased by partially closing the condenser iris.

Becke line

47 When high relief is observed, it is important to know whether a higher or lower RI liquid should be tried. Partially closing the condenser iris to give an axial beam will result in refraction of the light owing to the differences in RI between the liquid and the particle, forming a bright halo at the edge of the particle. To determine whether the particle has a higher or lower RI than the mounting liquid, the movement of the halo is observed as the focus is lowered or raised. In most microscopes the stage is moved: when the stage is lowered (the equivalent of a raised focus) the halo or Becke line moves towards the medium with the higher RI. For fine fibres the effect is best observed using a high magnification objective. When the RIs of the liquid and particles are close, dispersion causes two Becke lines to appear; the red line moves into the particle and the blue line moves into the liquid.

Dispersion staining

48 Dispersion is a term used to describe the variation in RI with the wavelength of light. Differences in dispersion between particles and liquids mean that even though the RIs match at one wavelength, they may be quite different at others. This leads to colour effects when fibres are observed in matching RI liquids using white light. It is easiest to observe small bright particles against a black background; hence a central stop in the back focal plane of the objective is used with an axial beam of light produced by the condenser iris.[24] Another method which produces a coloured image on a grey background, is to use a phase contrast objective with a corresponding phase annulus in the condenser. In both cases, the colours observed depend on the precise wavelength at which RIs for the liquids and fibres match. Dispersion staining is a particularly valuable technique for routine identification of asbestos in commercially produced products.[24, 39]

(1) Dispersion staining objective - central stop (saturated colours on a black background):

Fibre RI > > Liquid RI	White
Fibre RI > Liquid RI	Purple-red/Orange/Yellow
Fibre RI = Liquid RI	Purple
Fibre RI < Liquid RI	Blue/Blue-green
Fibre RI < < Liquid RI	White

(2) Positive phase contrast (desaturated colours on a grey background):

Fibre RI > Liquid RI	Thin fibres darker than background; thick fibres can show light in centre of fibre with thin dark outline.
Fibre RI = Liquid RI	Blue colour to fibre, with a diffuse red or orange halo.
Fibre RI < Liquid RI	Thin fibres lighter than background; thick fibres can show dark shading in centre of fibre.

49 Different colours will be observed with the dispersion staining objective when the fibre is oriented parallel or perpendicular to the polariser, arising from the different RIs of asbestos fibres. Recording of the predominant colours is used to characterise the fibre RIs. In theory, the identification of commonly encountered asbestos fibres can be performed with a dispersion staining objective using five high dispersion liquids having the RI values 1.550 for chrysotile, 1.605 for tremolite and anthophyllite, 1.640 for actinolite, 1.670 for amosite and 1.700 for crocidolite. In practice, because of variations in the fibre composition according to source, a wider range of fibre RIs can be found and a more extensive range of RI liquids may be required to achieve RI match between fibre and liquid. Examples of the dispersion staining colours obtained with the HSE reference materials[32] are listed in Figure 3 and illustrated in colour plates 1 and 2.

COMMON PROBLEMS

Positive identification of certain amphibole fibres

50 To avoid mis-identification of the amphibole type, it is important that all the required observations are made and compared against observations made for reference asbestos fibres, exhibiting properties such as those listed in Figure 3. RI ranges in Figure 3 have been taken from two literature sources: those quoted for chrysotile, amosite and crocidolite respectively were obtained from commercial asbestos fibres;[40] those quoted for anthophyllite, tremolite and actinolite were obtained from non-commercial asbestos fibres.[41] However, it should be noted that the optical properties alone may not be sufficient to distinguish between tremolite and actinolite from some sources (because these minerals are members of a 'solid solution series' for which there is continuously varying composition giving a continuous range of RIs[24]), or between tremolite and anthophyllite (because they have similar birefringence and RI ranges). When such distinctions are critical, additional methods of analysis (for example analytical electron microscopy, X-ray diffraction or infra-red spectroscopy) should be used (see also paragraph 6). If only PLM is available, examination of acicular non-asbestos forms of the associated minerals (which may be present in the sample) can be helpful in making the distinctions.

Differentiation between asbestos and elongated mineral fragments

51 Amphibole minerals are often coarse with prismatic or lath-like crystals which tend to break along two sets (at 60° to each other) of parallel planes of weakness within the atomic lattice known as cleavage planes. As a result the dust produced tends to contain a number of elongated fragments having sizes within the definition of a regulated fibre (longer than 5 μm, diameter less than 3 μm and aspect ratio >3:1, as used for fibre counting[26]). These elongated fragments have important properties which distinguish them from asbestos.[35,42] In some circumstances the analyst may need to identify elongated particles and decide whether they are mineral fragments or asbestos fibres. All of the non-asbestos amphibole minerals, including non-fibrous forms of anthophyllite, tremolite and actinolite, have three vibration planes and three different RIs. Anthophyllite is orthorhombic and hence exhibits parallel extinction. The other relevant amphiboles are monoclinic and (depending on crystal orientation) this can result in extinction occurring when the elongated crystal axis forms an angle up to 20° with the vibration directions of the crossed polars. If a crystal exhibiting maximum extinction angle is reoriented about its long axis, it will show parallel extinction.

52 Asbestos fibres are mineralogically anomalous in effectively showing only two RI vibration planes and consistent parallel extinction.[35,36,42] This is because even the very thin fibres that can be viewed in the polarised light microscope consist of bundles of polyfilamentous crystals with each crystallite randomly oriented along the length of the bundle. The difference between the extinction characteristics, together with the fibrous morphology described in paragraph 37, is used as the basis of the polarised light microscopy discrimination between asbestos and amphibole mineral fragments.

Heated asbestos [21-23]

53 Certain changes occur when asbestos is progressively heated. Therefore care should be taken if sample preparation involves heating the asbestos-containing material. Prolonged exposure to temperatures of 300 to 500°C of crocidolite and amosite causes colour changes, and increases in both RIs and the birefringence. For crocidolite, the changes with heating are: the sign of elongation reverses and the colour changes through grey then yellow to orange-brown; pleochroism is suppressed at the grey colouration stage, but reappears on further heating. For amosite the sign of elongation remains positive (length slow) but the colour changes through yellow to a dark brown, and pleochroism is observed. Thus, heat degraded crocidolite and amosite are effectively indistinguishable by light microscopy after exposure to temperatures above about 500°C. The RIs of chrysotile increase after significant exposure to temperatures of about 600°C or greater: the birefringence decreases, and in a few cases the sign of elongation changes to negative (length fast) and the fibres become pale brown. The alteration of asbestos by heat is dependent upon both the duration and the temperature of exposure. Prolonged exposure to high temperatures can result in complete degradation (for example, of furnace linings) but with judicious sampling unaffected fibres can often be detected in peripheral locations or in debris which became detached during installation.

Fibres with morphological and/or optical properties similar to asbestos

54 Most of the fibres discussed in the following paragraphs occur infrequently in samples presented for analysis. However, analysts need to be aware of their existence and distinguishing characteristics in PLM. Five types of fibre which can resemble chrysotile are discussed in paragraphs 55 to 59. Some mineral fibres which superficially resemble amphiboles are discussed in paragraphs 60 to 62.

55 Polyethylene is the most important of the interfering fibres because it is used as an asbestos substitute. Shredded polyethylene resembles chrysotile.[24] In RI liquid 1.550 the fibres dispersion stain with colours which appear typical of chrysotile (although more experienced analysts will observe desaturation of the blue colour across the fibres because of the low RI in this direction). The birefringence is higher than that of chrysotile, but the fibres are thin and hence generally show only first order white interference colours. If polyethylene is suspected, the melting of fibres on a hot plate or in a flame will distinguish them from chrysotile.

56 Leather swarf fibres have low birefringence and similar dispersion staining colours to chrysotile.[43] At low magnification (100x) they appear to have similar morphology to chrysotile, but they usually have clearly visible uniform fibrils. Chrysotile fibrils are too small to be

seen by PLM, although less uniform bundles of fibrils (fibres) are visible. In most instances the differences between chrysotile and leather swarf can be detected during examination with the low power stereo microscope: the material handles differently during examination under the stereo microscope. If leather is suspected as being present, the sample may be ashed at 400°C to remove it, and then re-examined for identification of asbestos. Care should be taken not to let the sample temperature rise above 600°C (see paragraph 53).

57 Macerated aramid fibres may appear to have a morphology similar to chrysotile but are recognisable by their extreme birefringence showing high order white interference colours. When mounted in RI liquid 1.640 they will show highly variable relief as the stage is rotated, because the lowest RI (across the fibre) is close to 1.64, while the higher RI (along the fibre) is of the order 2.4.

58 Spiders' webs, and natural organic fibres such as paper and feathers, have RIs close to those of chrysotile and show similar interference colours between crossed polars. In a clean sample, the morphology will distinguish them from chrysotile. However, in a sample containing a lot of particulates, sometimes only a small portion of fibre can be observed due to obscuration by the particles and this can lead to misidentification. Again these fibres can be removed by ashing the sample or exposing individual fibres to a flame (but refer to paragraph 53 for changes to asbestos which may occur on heating).

59 Talc fibres are thin ribbons which may be recognised by characteristic morphological twists and kinked bent forms. They have a higher RI than chrysotile parallel to the fibre length (in the range 1.589 to 1.600, giving a dispersion staining colour pale yellow in RI liquid 1.550). The other two RIs of talc are in the ranges 1.539 to 1.550 and 1.589 to 1.600,[3] and are observed perpendicular to the fibre, at different orientations as the fibre is 'rolled' (with a dispersion staining objective, blue and pale yellow in RI liquid 1.550).

60 Fibrous Brucite (Nemalite) normally consists of straight white to pale brown fibres but lacks the tensile strength of asbestos, is brittle and is soluble in acid.[24] It has a negative sign of elongation (length fast) which reverses to positive (length slow) when heated. It is distinguished from asbestos by its RIs which are in the range 1.560 to 1.590 parallel to the fibre and 1.580 to 1.600 perpendicular[3] (with central stop dispersion staining giving colours of yellow to pale yellow in RI liquid 1.550, or pale blue in RI liquid 1.605).

61 Fibrous Wollastonite has an acicular morphology,[24] is very brittle, white in appearance and soluble in acid. It has RIs which overlap with tremolite, actinolite and anthophyllite although it has lower birefringence and always displays an extinction angle. The RI almost parallel to the fibre is in the range 1.628 to 1.650. The other two RIs are in the ranges 1.626 to 1.640, and 1.631 to 1.653, and are observed across the fibre, at different orientations as the fibre is rolled.[24] A distinctive feature is that the RI along the fibre is intermediate between the two RIs observed at the different orientations across the fibre as the fibre is rolled. Thus examination of many fibres with crossed polars and first order red compensator will show most as length slow (as the fibre is lath-like and has a preferred orientation); other orientations may appear as length fast. Gentle pressure on the coverslip with a needle can be used to rotate a fibre and show it to appear both length fast and length slow.

62 Diatamaceous earth may show acicular fragments with the appearance of fibres. However, the low RI of 1.42 will easily distinguish them from asbestos fibres using dispersion staining techniques. The characteristic morphology is recognised at magnifications around 500x.

Identification of other sample components

63 A laboratory conducting routine analysis selectively removes fibres for examination and ignores the majority of the non-asbestos materials. The composition of many asbestos products is relatively uniform during manufacture and a wider knowledge of materials identification can be helpful in recognising many common products or formulations.

QUALITY ASSURANCE (QA) AND QUALITY CONTROL (QC)

64 A routine QA programme to assess the quality of the results produced by the PLM laboratory must be developed and implemented. The purpose of a QA programme is to ensure that the sampling, analysis, recording and reporting of the results all meet acceptable standards. A QA programme will usually have a written protocol to describe how each stage of the procedure is conducted and will define the types of QC measurements and checks that are required. Many of the required procedures are covered in the NAMAS accreditation scheme for asbestos sampling and identification.[30]

65 Intra-laboratory performance testing is necessary to confirm that the analyst can maintain performance with time, and standards should be set to measure whether or not analytical performance is adequate to meet the quality objectives of the laboratory. Various ways in which this can be achieved are described in other HSE guidance (MDHS 71).[44] Ideally, performance testing should be conducted 'blind' and should involve everyday commercial samples, along with the less common asbestos types and fibrous materials which resemble asbestos, as well as the three main commercial asbestos minerals.

66 Microscopes and ancillary equipment must be maintained in good order, and alignment checks should be conducted prior to analysis. RI liquids can become contaminated through improper use, resulting in a change of RI or the introduction of fibres from samples. Routine monitoring checks for contamination should be performed and recorded[30] (see also paragraph 19).

67 Training is of fundamental importance to both sampling and analysis. If an asbestos building survey is conducted, the training and experience of the sampler will control the quality of the survey. Microscopic determination of asbestos requires the analyst to make repeated assessments of a number of physical properties and maintain consistent diligence in the search for fibres. Many

of the procedures rely on the quality of judgement of the analyst as well as correct use and alignment of the microscope and detailed recording of the properties tested. Analysts should be thoroughly familiar with the appearance and characteristics of asbestos when viewed by a stereo microscope, and by the various modes of operation of the polarised light microscope. Ideally, the analyst should have specialised training in asbestos identification. Also, experience is very important and until analysts are fully trained, all their analyses should be checked by an experienced analyst. An adequate laboratory QA programme will contain detailed descriptions of the training programme, together with the training records of each analyst. The minimum requirement is that an analyst must be able to identify representative (well-defined) fibres of the six regulated asbestos types. Reference fibre standards have been prepared on behalf of HSE for this requirement[32] and may be obtained from the supplier listed in Appendix 2. In addition, samples chosen for the training programme should typify the range of materials analysed by the laboratory.

68 Colour or other vision defects need not disqualify a prospective analyst, provided that the individual is able to properly assess the optical characteristics described in this method, and achieve a satisfactory standard of performance in a quality assurance scheme. An HSE Medical Series Guidance Note MS7 on colour vision[45] is available, which includes a list of colour vision tests. (The most recently developed is the 'City University' test, 1973.) Currently, NAMAS requires that all identification analysts undergo a suitable test (such as the Ishihara test[30]).

ADVICE

69 Advice on this method may be obtained from the Minerals and Fibres Section, Health and Safety Laboratory, Health & Safety Executive, Robens Building, Broad Lane, Sheffield S3 7HQ. Suggestions for improvement should also be sent to this address.

ACKNOWLEDGEMENT

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APPENDIX 1 A Glossary of Terms

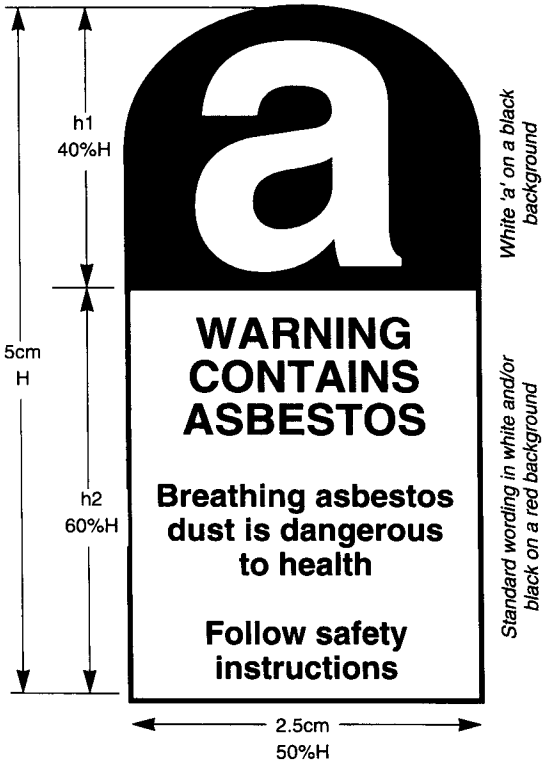
Term (and paragraph of first appearance)	*RMS Dictionary of Light Microscopy:*[2] *Preferred term: Definition.*
Achromat (22)	Achromat: a microscope objective in which chromatic aberration is minimised for two wavelengths (one less than about 500 nm, and the other greater than about 600 nm), and spherical aberration and other aperture dependent defects are minimised for another wavelength (usually about 550 nm).
Analyser (21)	Analyser: a polar used after the object (usually between the objective and the primary image plane) to determine optical effects produced by the object on the light, polarised or otherwise, with which it is illuminated.
Becke line (45)	Becke line: a bright line (due to refraction and/or diffraction) formed in the image at the boundary between media of different optical pathlengths. It moves in the direction of the longer optical path when the distance between the objective and the object is increased. Note: this phenomenon is used to recognise relative differences in RI of two adjacent media, eg a particle and the surrounding medium; when the RIs are matched the Becke line disappears.
Bertrand lens (21)	Lens, Bertrand: an intermediate lens which transfers an image of the back focal plane of the objective into the primary image plane; used for conoscopic observation in polarised light microscopy and for adjustment of the microscope illumination system especially with phase contrast microscopy.
Birefringence (40)	Birefringence: the qualitative expression of the maximum difference in RI due to double refraction (symbol n).
Compensator (21)	Compensator: a retardation plate (sometimes of variable optical pathlength difference) used to measure the optical pathlength differences within an object.
Condenser (21)	Condenser: a part of the illumination system of the microscope which consists of one or more lenses (or mirrors) and their mounts, usually containing a diaphragm, and is designed to collect, control and concentrate radiation.
Dispersion Staining (6)	Microscopy, Dispersion Staining: the microscopy of transparent objects which are in a mounting medium, the RI of which matches that of the object for a certain wavelength, but which has a distinctly higher dispersive power than the object. Under these conditions, both the object and the mounting medium appear coloured near their interfaces. The colour with which the object appears is distinctly different from that with which the mountant appears. The colours and their differences depend on the wavelength at which the RIs of the object and medium match and the kind of microscopy used; dispersion staining may be used in bright-field microscopy, the colour being concentrated in the Becke line, in darkground microscopy or in phase-contrast microscopy.
Eyepiece (21)	Eyepiece (or ocular): A lens system which is responsible for the angular magnification of the final virtual image formed by it from the primary image. This image is converted into a real image by the observer's eye or other converging lens system.
First order red (21)	Red, first order (sensitive tint): the characteristic reddish violet interference colour at approximately 530nm retardation.
Focal plane (22)	Focal plane: (1) a surface connecting all the points at which bundles of parallel rays entering an ideal converging lens cross on the other side of the lens, and thus containing a focal point; (2) a surface at right angles to the optical axis of a lens (or mirror) in which the image of an object lying at infinity is formed: it is one of the cardinal planes.
Focusing eyepiece (21)	Eyepiece, focusable: an eyepiece with a mechanism for focusing an (interchangeable) graticule or diaphragm mounted within it and coinciding with the primary image.
Iris (21)	Iris: a diaphragm bounded by multiple leaves, usually metal, arranged so as to provide an opening of variable size which is adjustable by means of a control.

Koehler Illumination (21)	Köhler Illumination: a method of illuminating objects in which an image of the source is projected by a collector into the plane of the aperture diaphragm in the front focal plane of the condenser. This latter, in turn, projects an image of an illuminated field diaphragm at the opening of the collector into the object plane.
Numerical Aperture (21)	Numerical aperture: a number (often symbolised by the letters NA) originally defined by Abbé for objectives and condenser. It is given by the expression 'n. sin u', where 'n' is the RI of the medium between the lens and the object and 'u' is half the angular aperture of the lens.
Objective (21)	Objective: the first part of the imaging system, consisting of a lens, its mount, and any associated parts. It forms a primary image of the object.
Phase (21)	Phase: relative position in a cyclical or wave motion; it is expressed as an angle, one cycle or wavelength corresponding to 2π radians or to 360°.
Pleochroism (33)	Pleochroism: the property of an optically anisotropic medium by which it exhibits different brightness and/or colour in different directions of light propagation, or in different vibration directions, on account of variation in selective spectral absorption of transmitted light.
Polarised Light (5)	Light, Polarised: light in which there is only one vibration direction.
Polariser (21)	Polariser: a polar placed in the light path before the object.
Power (5)	Magnifying Power: the ability of an optical system to produce a magnified image under specified working conditions (for example the optical fitting dimensions). The magnifying power is expressed as the lateral or angular magnification of the image under consideration.
Refractive Index (5)	Refractive Index: the ratio of the speed of light (more exactly, the phase velocity) in a vacuum to that in a given medium (symbolised by the letter n or n').
Retardation (21)	Retardation: the slower propagation of a wavefront in a medium of high RI as compared with that in a medium of low RI.
Stage (21)	Stage (Microscope Stage): the platform, at right angles to the optical axis of the microscope, which carries the object. It is often fitted with mechanical movements (as in a mechanical stage) to allow easy positioning of the object in the 'x' and 'y' axis and movement along, and rotation about, the 'z' axis.
Stereo Microscope (5)	Microscope, Stereo: a binocular microscope in which the object is observed by each eye from a slightly different angle. Disparate image points will be imaged on corresponding points of the retina and thus cause stereoscopic perception.

APPENDIX 2 Suppliers of Equipment and Services

Equipment/Service	*Supplier*
Asbestos Reference Samples	Institute of Occupational Medicine 8 Roxburgh Place Edinburgh EH8 9SU (031-667 5131)
Cargille Refractive Index Liquids	McCrone Scientific Limited 73 Maygrove Road London NW6 2BP (071-624 5409)
NAMAS Accreditation	National Measurement Accreditation Service National Physical Laboratory Teddington Middlesex TW11 0LW (081-943 7140)

APPENDIX 3 Asbestos label



APPENDIX 4 Sample Packaging and Transport

Bulk samples of asbestos materials taken on site will usually have to be transported to the laboratory for analysis. The road transport of material containing asbestos in a receptacle of capacity of 5 litres or more is subject to the provisions of the Road Traffic (Carriage of Dangerous Substances in Packages etc) Regulations 1992. These regulations include specific requirements for packaging and labelling and stipulate that the package is accompanied by information in writing to indicate the nature of the hazards to which it could give rise. The vehicle used may require to be placarded and the driver to be appropriately trained (see the Road Traffic (Training of Drivers of Vehicles Carrying Dangerous Goods) Regulations 1992).

Transport of asbestos by other modes in appropriate quantities may be subject to similar provisions. If asbestos is to be transported internationally in other than limited quantities, other requirements must be met and the advice of the Department of Transport should be sought.

For limited quantities outside the scope of the regulations, each sample should be placed in an individual airtight container, sealed and labelled with a unique identifier. Because the outside of the container may be contaminated in the sampling procedure, the container sample or samples should be placed in a second airtight container which should bear an appropriate warning label (see Appendix 3). Further outer packaging is permissible.

APPENDIX 5 Movement and Disposal of Waste Asbestos

Bulk samples of asbestos materials that have been analysed by PLM, become waste asbestos and will require safe disposal.

The movement of certain types of waste asbestos or waste material contaminated by asbestos, is subject to the pre-notification and consignment note procedures in the 1980 Special Waste Regulations. There is no exception for small quantities; but DOE has advised in paragraphs 7 and 8 of Circular 4/81 that a common sense approach should be adopted, where it is clear that it is not necessary to apply the full range of control to small quantities of special waste. In view of this, small quantities of special waste (for example, small numbers of 5 cm^3 samples requiring disposal after analysis) may be regarded as 'de minimis' and not subject to the 1980 Special Waste Regulations controls. In any other case, or if in doubt, enquiries should be made to the Waste Regulation Authority for the site in question, and their advice about the application of the Regulations must be followed.

Controlled wastes which are not 'special wastes' are subject to the normal controls, for example the Code of Practice made under the Environmental Protection Duty of Care Regulations 1991 (SI 2839).

DOE advice on the safe movement and final disposal of

asbestos waste is contained in Waste Management Paper 18, which recommends that the waste is placed in heavy duty plastic bags and sealed, marked, and arrangements made for its disposal by landfill at suitably licensed waste disposal facilities. The Code of Practice for the Disposal of Asbestos Waste from the Institute of Wastes Management expands upon and brings up-to-date the information contained in DOE guidance.

Note: Appendices 4 and 5 were contributed by staff from the Department of the Environment; the following details relate to documents mentioned therein:

(i) Department of the Environment Circular 4/81: Welsh Office Circular 8/81 Control of Pollution Act 1974 *Control of Pollution (Special Waste) Regulations 1980*
ISBN 0 11 751510 8

(ii) Institute of Waste Management *Code of Practice for the Disposal of Asbestos Waste* October 1988
ISBN 0 90 294417 7

(iii) Department of the Environment Waste Management Paper No 18 *Asbestos Wastes* HMSO 1979
ISBN 0 11 751 384 9.

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